# Advanced Vehicle and Fueling Infrastructure Evaluation
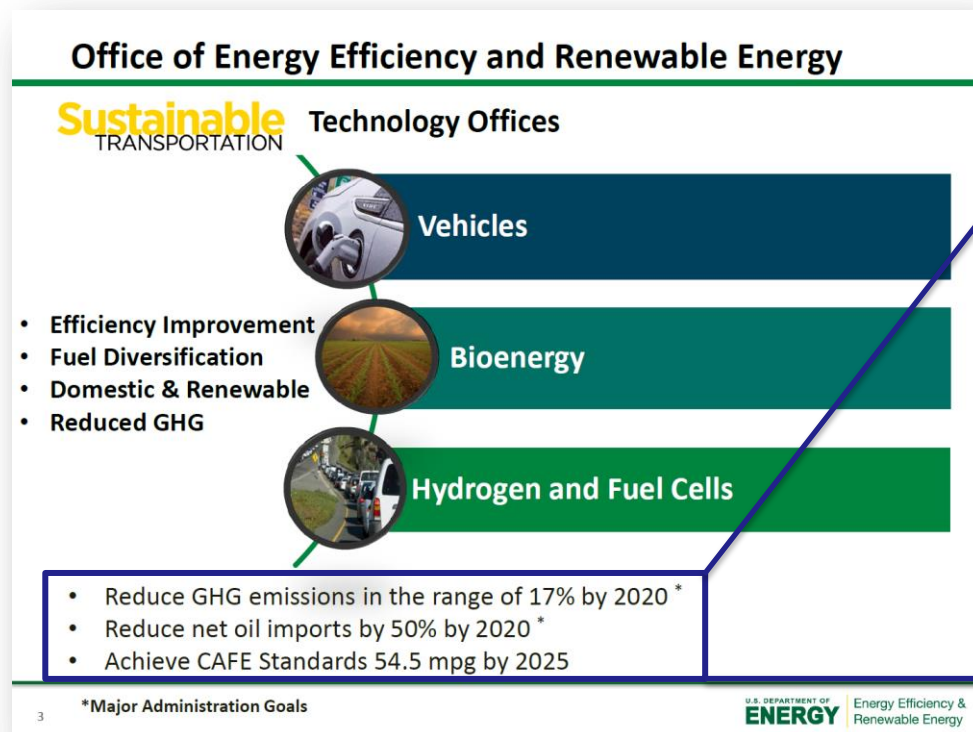
**John Smart**
INL/MIS-15-35328

*INL Tech-to-Market (T2M) Workshop*      *May 19-20, 2015*

# *Advanced Transportation Core Customer:*
## *U.S. Department of Energy's Office of Energy Efficiency & Renewable Energy (EERE) Sustainable Transportation*

- **EERE is split into three areas:**
  - **Renewable Energy: $370M**
  - **Energy Efficiency: $664M**
  - **Sustainable Transportation: $558M**



**Office of Energy Efficiency and Renewable Energy**

**Sustainable** TRANSPORTATION **Technology Offices**

- Vehicles
- Bioenergy
- Hydrogen and Fuel Cells

- Efficiency Improvement
- Fuel Diversification
- Domestic & Renewable
- Reduced GHG

- Reduce GHG emissions in the range of 17% by 2020 *
- Reduce net oil imports by 50% by 2020 *
- Achieve CAFE Standards 54.5 mpg by 2025

*Major Administration Goals

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

**Drivers of Technology:**
- **Reduce GHG emissions by 15% by 2020**
- **Reduce net oil imports by 50% by 2020**
- **Achieve 54.5 mpg CAFE standard by 2025**

# *Additional (Larger) Drivers for Advanced Transportation*

## Regulation at the State Level

**California Air Resource Board (CARB) introduced the Zero Emission Vehicle (ZEV) mandate starting in 1990 in order to:**

1. **Reduce smog**
2. **Reduce greenhouse gas**
3. **Promote cleanest cars**
4. **Provide fuels for cleanest cars (electricity & hydrogen)**

**California Environmental Protection Agency**
**Air Resources Board**

**Zero Emission Vehicle (ZEV) mandate drives sales in California**
- **7500 ZEVs 2012-2014;     25,000 ZEVs 2015-2017**

**10 other states will mandate the same:**
- **Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, and Vermont**

**ZEV credits have their own market…**

# *Advanced Transportation: Drivers & Gaps*

## Drivers

- **High level goals at the federal Level - DOE-EERE:**
  - **Reduce GHG emissions by 15% by 2020**
  - **Reduce net oil imports by 50% by 2020**
  - **Achieve CAFE standards 54.5 mpg by 2025**

- **State level mandates driving sales - CARB:**
  - **Reduce Smog / Reduce greenhouse gas**
  - **Promote Cleanest Cars /Provide Fuels for Cleanest Cars (electricity & hydrogen)**
  - **7500 ZEVs between 2012 - 2014; 25,000 ZEVs between 2015 - 2017**

## Gaps

1. **Cost of vehicle is prohibitive to consumer**
2. **Vehicle does not meet the precieved needs of the consumer (range, fueling time, infrastructure accessibility / cost / convenience)**
3. **Infrastructure / fuel is cost-prohibitive or does not exist**

# INL's Advanced Transportation Activities

- **Attacking the key challenges of cost, consumer acceptance, and infrastructure to overcome barriers to alternative-energy vehicle adoption**

## Battery Performance & Life Testing and Diagnostics

- **Cost reduction**
- **Safety and life improvements**
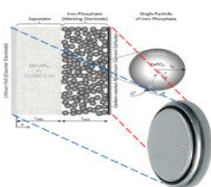


## Real-time Power and Energy Systems Emulation & Simulation

- **Added-value hydrogen production**



**Performance Science**



Advanced Batteries

Advanced Vehicles & Fueling Infra-structure

$H_2$ & Fuel Cells

Bioenergy Feedstock

**Performance Science**

## Big Data

- **Understanding consumer experience with alternative-energy vehicles and infrastructure**



## Electric Vehicle Charging Infrastructure

- **Supporting the development of global standards**

## Bioenergy Feedstocks

- **Cost reduction**
- **Quality improvement**
- **Scale-up and integration**

# Battery Test Center and Advanced Vehicles

**Development of next-generation low cost / reliable batteries**

- Leverage unique INL capabilities in Performance Science
- Foundation: Battery Testing Center & Advanced Vehicle Testing data collection
- Growth through strong partnerships with:
    1. DOE-EERE (USABC)
    2. OEMs
    3. Battery Developers
- Impact: Enabling and accelerating next gen-batteries
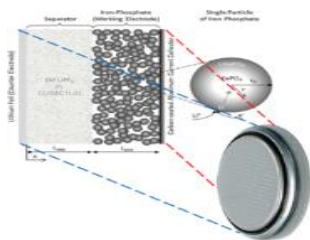
**Half-Cell / Coin**  **Pouch / Cell**  **Pack**  **Vehicle**

**Expansion of Performance Science lifecycle modeling**

# *Advanced Vehicles & Fueling Infrastructure*

## Understand the consumer experience with alternative-energy vehicles

- **Leverage unique INL capabilities in Big Data analysis**
- **Foundation: Advanced Vehicle Testing & EV Infrastructure Laboratory**
- **Growth: Steward to DOE-EERE, OEMs, SAE & CARB**
- **Impact: Increasing return on investment for alt-energy infrastructure development and deployment**

### *The EV Project*
- 8,000 Nissan Leafs and Chevrolet Volts
- 8,000 level 2 residential EVSE
- 5,000 level 2 commercial EVSE
- Up to 200 DC fast chargers
- 19 US cities

**Big Data Analysis**

**Heat maps of EV charging locations**

**Global standardization of wireless charging with SAE & OEMs**

**Alt-energy corridor analysis**

# *Advanced Vehicle Testing Experience*

- **Since 1994, INL and its partners have benchmarked PEVs in the lab, on the track, and on the road**
  - **INL has collected data from 232 million miles of driving and 44,300 AC MWh of charging from 27,400 electric drive vehicles and 17,000 charging units**

## Example: The EV Project

- **8,228 Leafs, Volts and Smart ED's**
  - **124 million test miles**
  - **At one point, 1 million test miles every 5 days**
- **12,363 EVSE and DCFC**
  - **4.2 million charge events**



**The EV Project**
- 8,000 Nissan Leafs and Chevrolet Volts
- 8,000 level 2 residential EVSE
- 5,000 level 2 commercial EVSE
- Up to 200 DC fast chargers
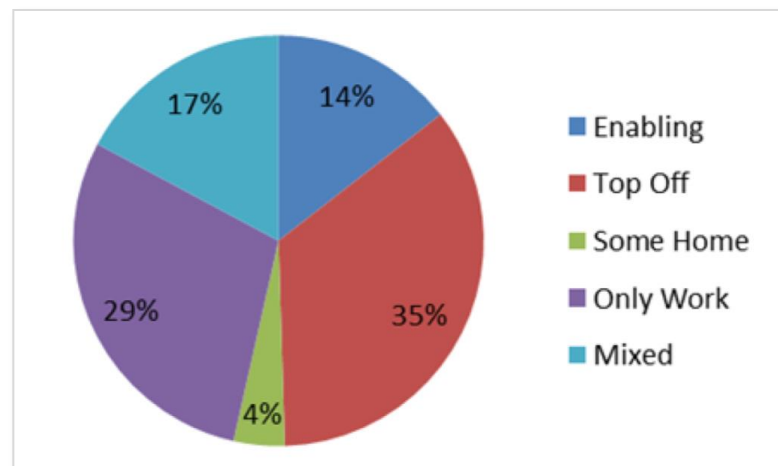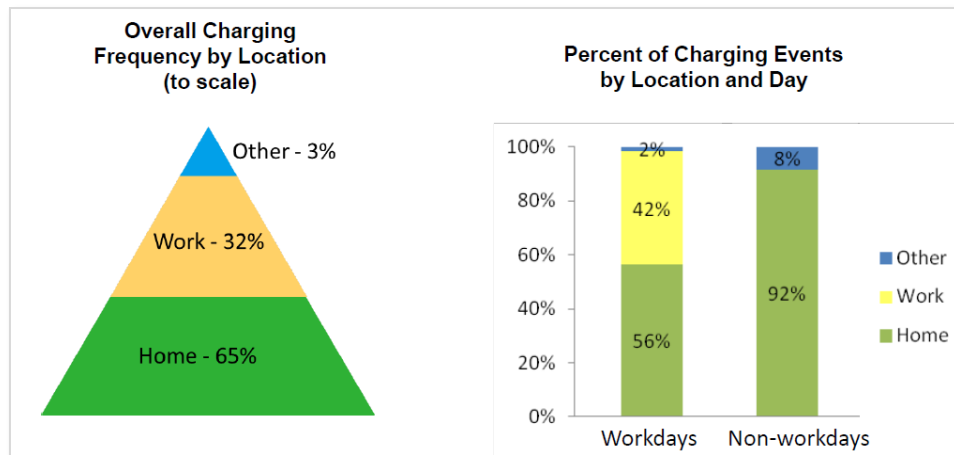- 19 US cities

# *Driving and Charging Behavior*

- **Analysis of driving behavior**
  - **Energy consumption**
  - **Usage patterns**
  - **Common parking locations**
- **Analysis of charging behavior**
  - **Utilization by time of day, location, and power level**
    - **Home vs. away from home**
    - **AC Level 1/2 vs. DC fast charge**
  - **Aggregate power demand**
  - **Impact of time-of-use electricity rates**
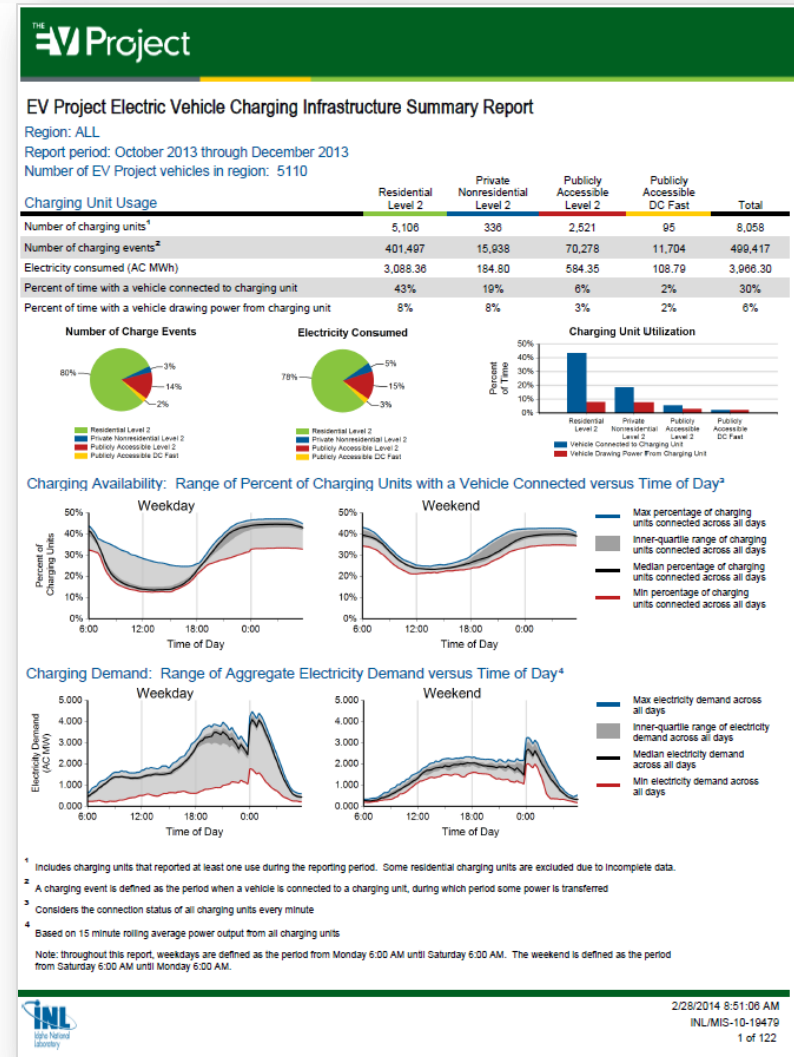
# *Workplace Charging Impact*

- **Most charging occurs at home and work**

- **Charging at "Other" locations may be critical to some drivers**

- **Workplace charging:**

  - **Enabled 14% of Leaf drivers to complete daily commutes that would have otherwise been impossible**

  - **Provided 15 mile average range increase on those days**

  - **Drivers averaged 12% more EV miles when they charged at work, regardless of need**

**Sample of Nissan Leafs in The EV Project whose drivers had access to charging at home and work**



Overall Charging Frequency by Location (to scale)
- Other - 3%
- Work - 32%
- Home - 65%

Percent of Charging Events by Location and Day

Workdays: Home 56%, Work 42%, Other 2%
Non-workdays: Home 92%, Other 8%



- Enabling 14%
- Top Off 35%
- Some Home 4%
- Only Work 29%
- Mixed 17%

# BEV, EREV, HEV, PHEV...



**BEV (Battery Electric Vehicle):**
Pure electric (no engine), charged by plugging in; typically with 75 - 100 mile electric range
**Full ZEV**



**EREV (Extend Range Electric Vehicle):**
Pure electric for 30 - 40 miles, then engine turns on for extended range
**Partial ZEV... but is it?**



**HEV (Hybrid Electric Vehicle):** Engine and battery power the wheels together. The battery is charged by the engine and regenerative braking
**PHEV (Plug-in Hybrid Electric Vehicle):** Similar architecture as HEV but battery can also be charged by plugging in; minimal all-electric range (5 - 20 miles)
**Both Partial ZEV**

# EV Miles Traveled (eVMT) Analysis Results

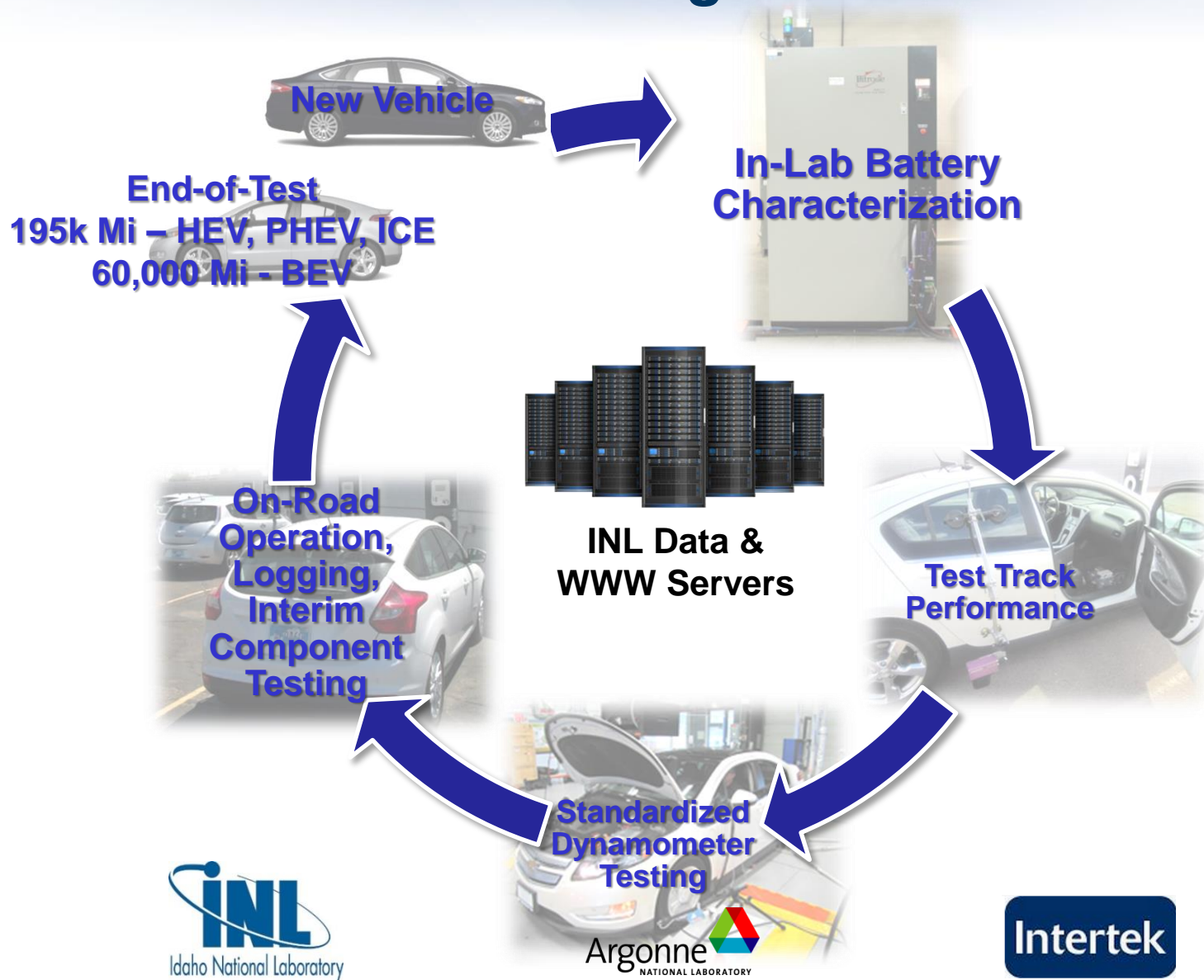| | BEV | | | EREV | PHEV | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nissan LEAF | Ford Focus Electric | Honda Fit EV | Chevrolet Volt | Ford Fusion Energi | Ford C-Max Energi | Honda Accord PHEV | Toyota Prius PHEV | Total |
| Number of Vehicles | 4,039 | 2,193 | 645 | 1,867 | 5,803 | 5,368 | 189 | 1,523 | 21,627 |
| Total Vehicle Miles Traveled *VMT* (miles) | 28,520,792 | 10,043,000 | 4,912,920 | 20,950,967 | 33,098,000 | 39,376,000 | 1,794,494 | 19,772,530 | 158,468,703 |
| Total Calculated Electric Vehicle Miles Traveled *eVMT* (miles) | 28,520,792 | 10,043,000 | 4,912,920 | 15,599,508 | 11,572,000 | 12,918,000 | 399,412 | 3,224,981 | 87,190,613 |
| Percent of EV-equivalent miles | 100% | 100% | 100% | 74% | 35% | 33% | 22% | 16% | |
| estimated Annual VMT | 9,697 | 9,548 | 9,680 | 12,238 | 12,403 | 12,403 | 14,986 | 15,136 | |
| estimated Annual eVMT | 9,697 | 9,548 | 9,680 | 9,112 | 4,337 | 4,069 | 3,336 | 2,484 | |
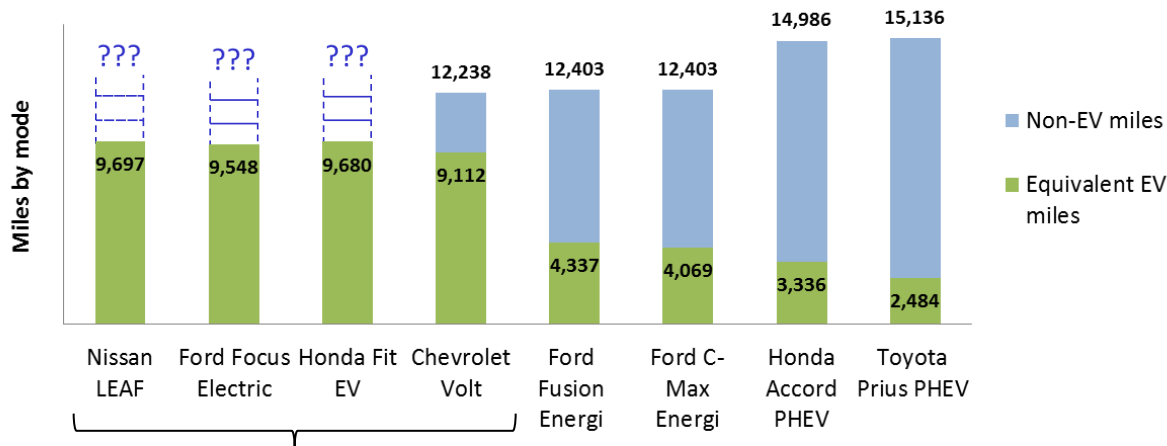


- EREV shows comparable eVMT as BEV
- Total VMT in households with BEV is unknown

# *Advanced Vehicle Testing Activity: On-road and Laboratory Testing and Evaluation*

# *Advanced Vehicle Testing Process*



New Vehicle

In-Lab Battery Characterization

End-of-Test
195k Mi – HEV, PHEV, ICE
60,000 Mi - BEV

On-Road Operation, Logging, Interim Component Testing

INL Data & WWW Servers

Test Track Performance

Standardized Dynamometer Testing

# High-mileage Fleet Evaluation Results

**Information and results published to AVTA website**

- **Baseline performance testing**
  - Specifications
  - Acceleration / braking
  - Test track energy consumption
- **Battery test results**
  - Capacity
  - Power capability
- **Fleet fuel economy relative to use and conditions**
  - Operation over vehicle life
- **Operating costs**
- **Maintenance history**



http://avt.inel.gov/phev.shtml
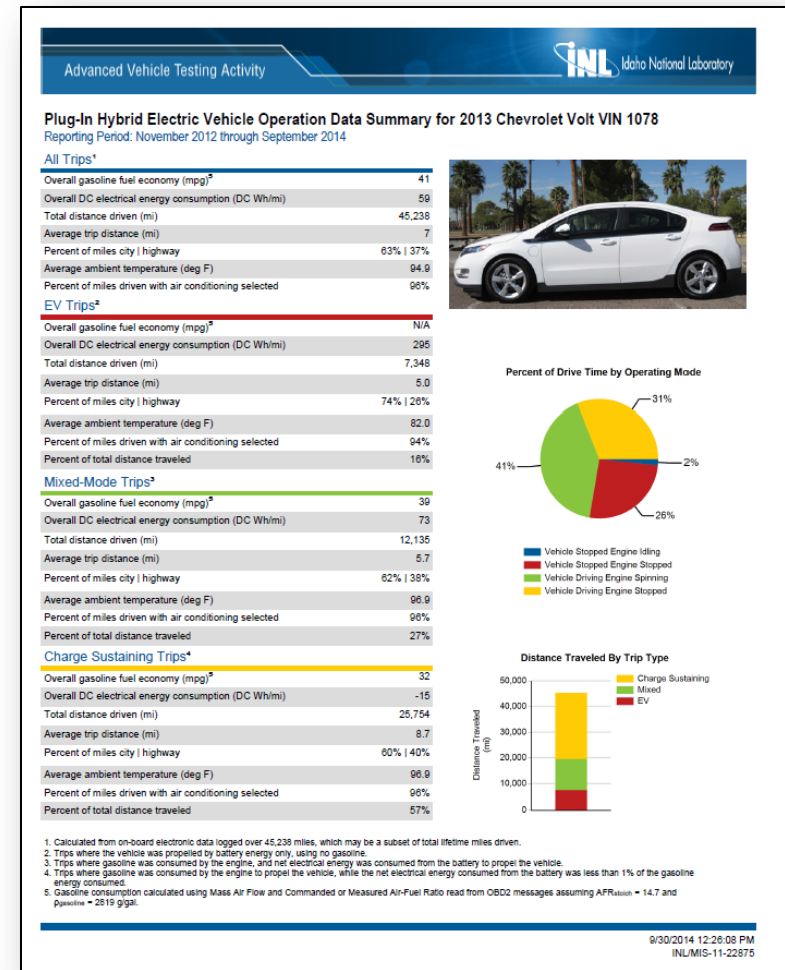
# Vehicle Charge Connection International Standards

- **Plug-In Vehicles can be charged at different voltages**
- **Lack of plug commonality limits consumer acceptance & marketplace penetration**

**AC Level 1 (120V)**
**Nissan Leaf: 10-12 hrs**

**AC Level 2 (240V)**
**Nissan Leaf: 4-6 hrs**



| | Type 1/USA | Type 2/Europa | GB/China |
|---|---|---|---|
| Alternating current (AC) | SAE J1772/IEC 62196-2 | IEC 62196-2 | GB Part 2 |
| Direct current (DC) | IEC 62196-3 | IEC 62196-3 | GB Part 3/IEC 62196-3 |

**DC Fast Charge (480V)**
**Nissan Leaf: 80% ~20 mins**

| | System A CHAdeMO (Japan) | System B CATARC (PRC) | System C COMBO1 (US) | COMBO2 |
|---|---|---|---|---|
| Connector | | | | |
| Vehicle Inlet | | | | |
| Communication Protocol | CAN | | PLC | |

# DC Fast Charging Impact Study on 2012 Leafs





**After 50,000 miles:**

- **NO appreciable difference in capacity loss (~2%) between AC Level 2 and DC Fast Charged packs**



Percent Loss Capacity Test Results
1011 L2   4882 L2   2183 DCFC   2078 DCFC
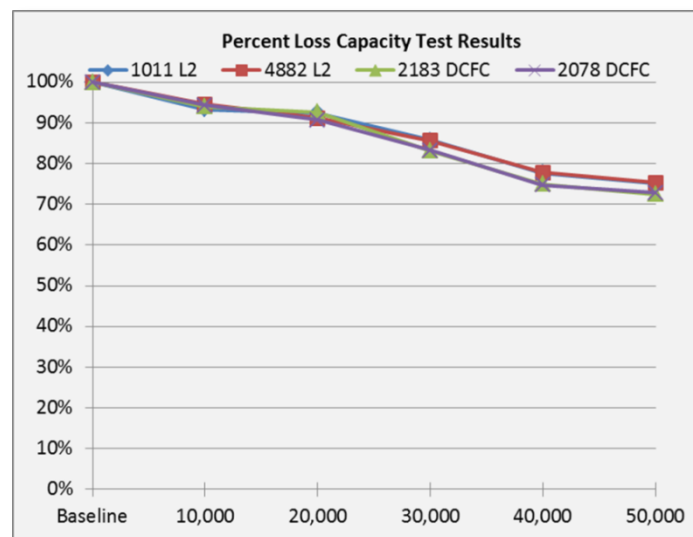
- **All Leafs were the same color – avoid unequal solar loading**

- **Leafs' climate control is set at 72°F year round**

http://avt.inel.gov/pdf/energystorage/DCFC_Study_FactSheet_50k.pdf

# *Advance Sustainable Transportation Summary*

- **With stretch targets to reduce green-house gas emission, improve CAFE mileages and decrease dependency on foreign oil, alternative-energy vehicles (electric, biofuel, hydrogen) will be continue to be developed regardless of the commodity price of oil**

- **Gaps towards achieving these targets are primarily around the cost of the alt-energy vehicle, its corresponding infrastructure / fuel and customer education**

- **INL is attacking these gaps across our Advanced Transportation activities**
    - **Reduction of battery costs**
    - **Consumer education with vehicles and fueling infrastructure**
    - **Fueling/charging infrastructure analysis and modeling**
    - **Fuel cost reduction of hydrogen / bio-fuels**